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FORTUNES IN WASTES AND FORTUNES IN FISH[1]

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I. INTRODUCTION.

WE have been at war with a well-organized nation which had planned and saved with war in view. In our belated endeavor to conserve existing resources and to develop new and latent ones, new problems arose and will continue to arise throughout the reconstruction period. Some of these concern fisheries and the pollution of waters. The United States Fish Commission has urged the public to eat fish, to make every day a fish day. This was no doubt done in the early days of our republic, for in a great strike of apprentices one of their chief demands was that they be not fed on salmon more than three times a week. Attention has accordingly been directed to the fact that where many fish ought to be there are few to be had. We find that fishes have greatly decreased. With only a brief survey of the situation one sees that the general problem of maintaining fishes against extensive catch and against pollution of waters with sewage and the waste products of manufactories is very complex. It is so complex indeed that in considering pollutions one may write only from his experience and knowledge without assuming to have covered or exhausted the field.

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[1] Contribution from the Illinois Natural History Survey and from the Zoological Laboratories of the University of Illinois, No. 124. For references to the literature of the subject and sources of information see, Bull. Ill. Nat. Hist. Surv., Vol. 13, Art. 12. The paper is the outgrowth of work done for the Nat. Hist. Surv.; The Dept. of Zoology, Univ. of Ill., supplied the illustrations. The writer is indebted to Professor S. W. Parr, Dr. Roger Adams and Mr. F. C. Baker for suggestions during the preparation of the manuscript.

The richness of the fish supply of our east coast in the early colonial days was beyond our wildest imagination. One early writer said of the shad of the Delaware and Susquehanna rivers, "They came in such vast multitudes that the still waters seemed filled with eddies, while the shallows were beaten into foam by them in their struggles to reach the spawning grounds." They swarmed every spring from mouth to headwaters of every river from Maine to Florida. Shad was undoubtedly the most important fish food in the early days of the nation. They were eaten fresh, and smoked and salted for winter use. During the spring runs people traveled long distances to shoal rivers to obtain their winter's supplies.

Along the Illinois River many years ago, buffalo-fish afforded the chief marketable species. These were caught by farmers, fishermen and others, and shipped by boat, principally to St. Louis. As no ice was used the fish frequently spoiled, or they were thrown away because the market was overloaded. Thus this great resource was depleted by careless and wasteful methods of catching and marketing.

The Atlantic salmon once entered all the rivers of New England; now it is the most expensive fish on the market. Our Great Lakes once yielded whitefish in abundance, but now the number is exceptionally small in comparison. Some of our Pacific-coast fisheries are likewise being depleted. Every stream formerly yielded fish to small boys and old men anglers. If any of these sources yielded half their original quantity it would now be counted a veritable fortune in fish.

Our fish resources have been depleted through neglect, carelessness and the pollution of waters. Such as are still left are endangered by new projects and new pollutions. There has been too much bald scientific and business sophistry in the matter. Ichthyologists, biologists, engineers, sanitarians, industrial chemists and business men, without consultation, cooperation or critical analysis, have proceeded on the basis of their imperfect and fragmentary knowledge to draw inferences as to the effect of this or that on fishes. The inferences of some scientists are not especially more in keeping with an equitable decision relative to a policy favorable to the public interest than was the exclamation of a manufacturer when confronted with a law intended to stop his factory from polluting streams: "What, stop a great industry because of a few fish!" The pollutions of manufacturing plants and city sewage have greatly aggravated the depletion, or in some instances have completed the destruction previously started by heedless fishermen; but the pollutions are far more serious than the initial injury because they preclude the possibility of easy recovery. We have all sinned alike until it becomes imperative that we take stock of our knowledge, now that we are under the pressure of numerous problems demanding immediate solution because of the great war and necessary reconstruction.

The damage done in our fresh waters by pollution and obstruction of streams with dams with no adequate fish ways is almost incalculable. The great increase in manufacturing in the past fifty years has loaded our streams with poisons which have seriously furthered the destruction of fishes that were formerly available everywhere. To be sure the Mississippi and its larger tributaries supply fish, particularly carp, in quantity to the market and in the Illinois River, for example, the number of fishes at points about 200 miles or more from Chicago has been increased by increasing breeding grounds and the fertilizing of the waters by the Chicago sewage. When one considers that fishes have been wiped out for about 120 miles to bring an increase this far down the river, the gain proves after all to be a loss. The importance of pollution has been little realized in America, but progress along these lines has been very slow everywhere.

In Scotland about the year 1220 it was ordained that from Saturday night to Monday morning it should be obligatory to leave a free passage for salmon in all the various rivers. Almost seven hundred years later a very similar law was enacted in certain of our Pacific states, but the time is shorter, being from Saturday night to Sunday night. The absence of such laws in New England a century ago has caused infinite damage to salmon and shad resources.

In 1606 an act passed by James VI. of Scotland forbad the pollution of lochs and running streams because it was hurtful to all fishes bred therein. The punishment for violations were severe. Three hundred and twelve years later we are confronted with a problem of substituting fish for beef, pork and mutton and find our laws no better than the laws of three to seven hundred years ago and the native fish supply very much reduced through heedlessness and pollution with waste.

These wastes are numerous and have been less often preserved in America than elsewhere.[2] Tar is an important waste substance. At one time coal-tar was considered a nuisance in gas-making, difficult to handle and difficult to dispose of. Tar is to be looked upon as the prize among waste products. It is unlikely that anything furnishing such an enormous number of useful substances will again be found nor can the enormous wastage of them in America be repeated again. The number of chemists who have investigated this substance is, of course, enormous. It was in 1856 that Sir William Perkin produced the first dye to be made in large quantity. He was a successful business man as well as a chemist, and built and operated a dye factory in England.

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[2] See "World Wide," Toronto, November, 1917.

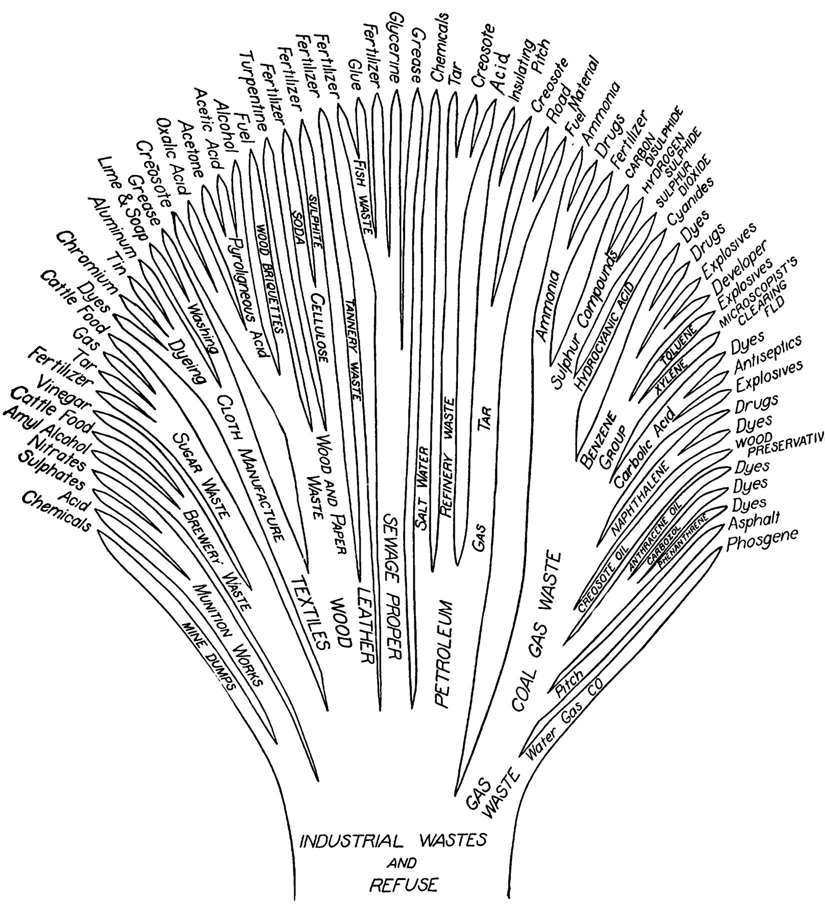


FIG. 1. Diagram showing, in the form of a tree, the various wastes and the useful substances into which they may be manufactured or which may be obtained from them.

There are numerous interesting cases of waste products that have proved gold mines to men who have found ways of turning them into something useful. The volatile substances given off in the making of charcoal from wood, for example, have become very important. In the old way of making charcoal all these valuable products (wood alcohol, acetone, acetic acid, etc.) were entirely lost, but to-day they are the most important of the substances obtained. The investigation of waste materials is often very fascinating, and sometimes leads to unexpected ends. This was the case with the waste earths from which materials used in the making of incandescent mantles had been removed. Small mountains of these wastes were

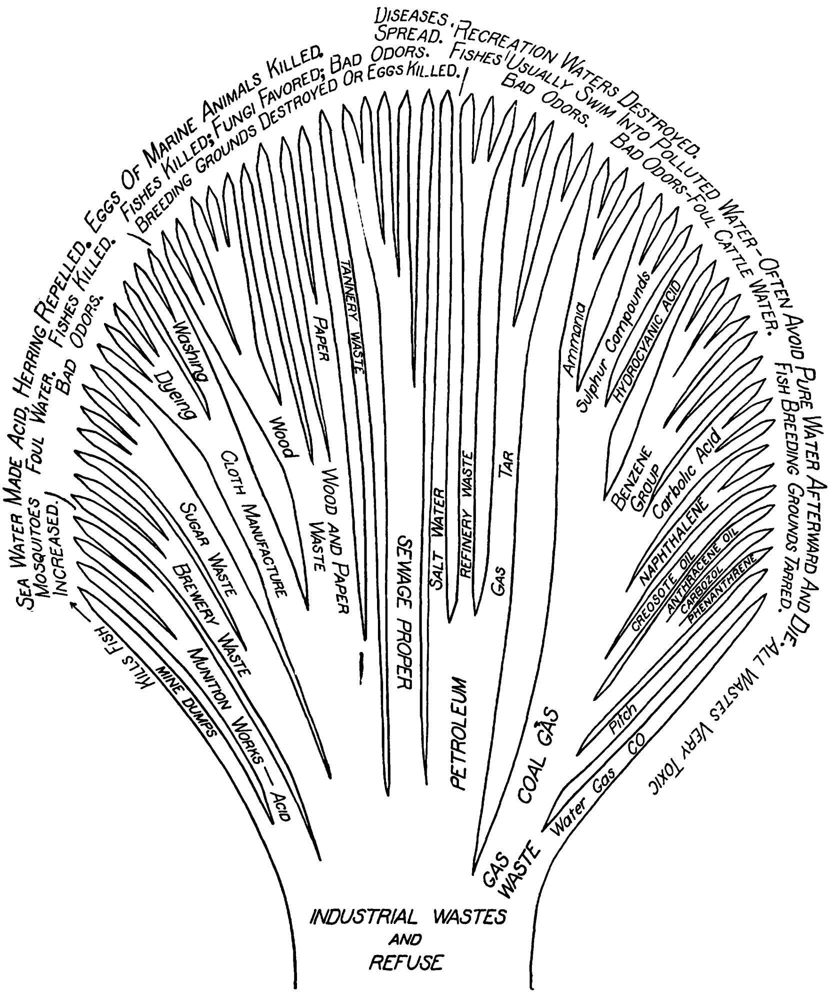


FIG. 2. Diagram showing the various wastes and the damage they do when **not** properly recovered.

accumulating and Baron von Welsbach went to work to investigate them for oxides other than those used in the manufacture of mantles. By means of electricity he reduced some of these oxides, obtaining certain lumps of metal. In cutting a lump with his knife, he discovered a remarkable sparkling effect. He soon saw that this had commercial possibilities, and the outcome of it was the preparation of a form of gas lighter to replace matches. These metals have also played an important part in the great war as flares for lighting no-man's-land and in furnishing the various types of signals. This was a very important waste product.

As the years go on waste products are constantly disappearing from European industry and to a lesser extent from American. Great competition and the lowering of prices have made it essential for factories to utilize or dispose of all their waste material, and processes that leave large margins for waste have not much chance of success. Utilization of waste is necessary in America now that we have to make up for the enormous wastage of war.

Perhaps most of what one may call the sensational discoveries with regard to waste substances have already been made; but there is still a great field for research both in recovering useful substances and in rendering residues harmless to animals. There is the wood-pulp industry, for example. Over 145,000 cords of pulp-wood, valued at $800,000, were lost annually in Canada, and also large quantities of sulphur from the chemicals used. The waste liquors containing these substances have been discharged into rivers or the sea and are very poisonous to animals. There is a good opportunity to utilize sawdust, and to get more value out of it than in the past. It has been used for making artificial silk, and also for manufacturing alcohol. If alcohol should come to be used in place of gasoline for automobiles, this would, in all probability, prove a profitable means of obtaining it.

It would be a very great advantage to the tanning industry if really good use could be found for the spent tan and the various waste liquors. These are now used as fertilizer. It is agriculture that seems to get the benefit of a large number of the odds and ends of waste substances. If one can find no other use for a waste material, he can probably work it off either as a cattle food or as a fertilizer though at a very low price. But one must not pass blissfully over the damage the substances do when wasted as shown in Fig. 1 and Fig. 2. The fishes must be considered. Attention is accordingly turned to some of the specific needs of fishes and fisheries.

II. Fresh-water Fishes

1. *Their Needs.*—The presence or absence of fishes is controlled by (*a*) their ability to recognize the presence of strange or deleterious substances and to turn back when they are encountered, and (*b*) by their survival or death in situations where they can not escape the deleterious conditions. The sense organs with which they recognize strange or deleterious substances have been shown to be very elaborate and effective. Fishes recognize exceedingly minute quantities of numerous substances, for example, two parts per million of sulphur diox-

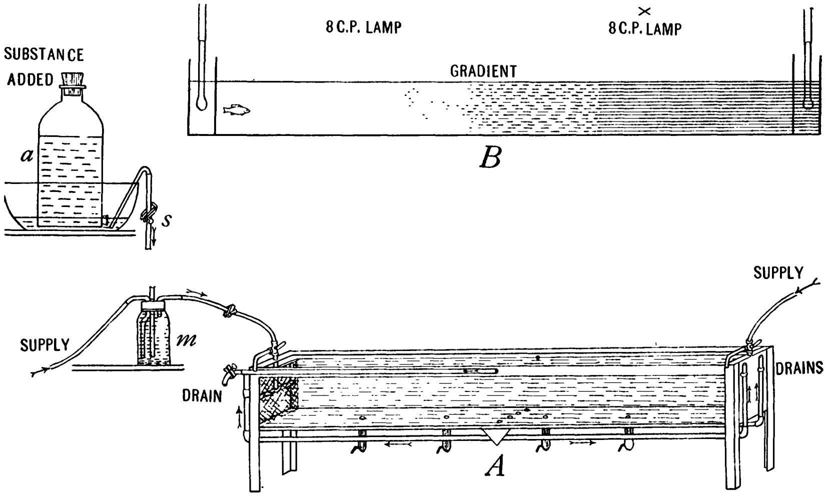


Fig. 3.

Fig. 3. Gradient Tank (*A*). Longitudinal Section of Tank (*B*). Fig. 3, *A*, The gradient tank and apparatus for introducing substances into one end. The water flows into the two ends of the tank from a common source. The flow is adjusted with a pinch cock on a rubber hose at the right-hand end, for example, at 500 c.c. per minute. This is done by turning the 3-way valve so as to run the water outside of the tank through the small spout which ends at the water level just outside of the tank. The water can be caught here in a graduate for a definite length of time and the flow per minute determined. The flow of water at the end into which the substance is added may be set at, say, 400 c.c. per minute and then sufficient of the solution added to the mixing bottle from the siphon above at the left (100 c.c.) to make this 500 c.c. also. The solution of a non-volatile substance is siphoned (see Fig. 1, *A*) from a dish in which is a 12-liter aspirator bottle (*a*) with the upper opening tightly corked and the lower one open. When the water in the dish falls below the level of the lower opening a few bubbles of air slip in and the same amount of fluid flows out, thus maintaining a constant level in the dish as long as the supply in the aspirator bottle holds out. Volatile substances have usually been added directly from the lower opening of the aspirator bottle. In this case it is necessary to correct the flows occasionally. The solution is run into a mixing bottle (*m*) which is connected in the flow of pure water. Fig. 3, *B*, shows a longitudinal section of the tank when a substance is introduced at the left-hand end. The substance is shown by black markings. The central portion shows a gradient between pure water (white) and the introduced substance (black lines). The graphs are drawn on the basis of the position of the fish in this longitudinal section.

ide, and not only turn back upon encountering them, but are able to recognize and orient their bodies with reference to increases and decreases of such substances often present in water.

The testing of these sensibilities of fishes has been carried on by means of experiments performed in a gradient tank, as shown in Fig. 3, *A*. Water of two kinds was used in the experiments. One kind was allowed to flow into one end at a definite rate and another kind into the other end at the same rate. The mixture flowed out at the middle, at the top and at the bottom so that the two kinds of water met at the center. The outflow at the center did not of course prevent the mixing of the two kinds of water in the tank and thus the middle section (broken line area in Fig. 3, *B*), equal to one half or one third of the tank, was a gradient between the two kinds of water. The tank used in these experiments was 122.3 cm. (49 in.) by 15 cm. (6 in.) by 13 cm. (5¼ in.) deep. The front wall was of plate glass and a plate glass top was used at times. Water was allowed to flow in at both ends at the same rate (usually 600 c.c. or about a pint per minute) through tee-shaped tubes, the cross bars of which contained a number of small holes. The cross bars of the tees were at the center of the ends of the tank behind screens. The drain openings were located at the center near the top and in the bottom. The outer openings of the drain tubes were at the level of the water in the tank. The water flowed in at the ends and drifted toward the center and flowed out through the drains. We found no evidence that fishes react to the slight current thus produced. Since each half of the tank held about nine liters (9½ quarts), it required 15 minutes to fill it or to replace all the water in one of the halves. The tank was enclosed under a black hood. Two electric lights were fixed above the center of the two halves, *i. e.*, above a point midway between the screen partition and the center drains. The light was 15–20 cm. (6–8 in.) above the surface of the water which was 13 cm. (5¼ in.) deep. The room was darkened during the experiments which were observed through openings in the hood above the lights or through the glass side late at night. Fishes do not usually note objects separated from them by a light.

Water differing as little as possible from that in which the fishes usually live was used for control readings. Controls were observed and the conditions in the two ends of these were the same either because the water introduced at the two ends was alike or because no water was run into either end (standing water). In the control experiments the two ends of the tank were alike and the fishes moved back and forth symmetrically (Chart I., Graphs 1 and 3; Chart II., Graph 5). When a gradient between two kinds of water was established, fishes put into the tank tend to go back and forth and thus encounter the experimental gradient. When the change of conditions thus encountered was such as to affect the fishes, they usually reacted either by turning back or by passing through the gradient into the treated water. But in the latter case they quickly returned to the untreated water, thus spending a shorter time

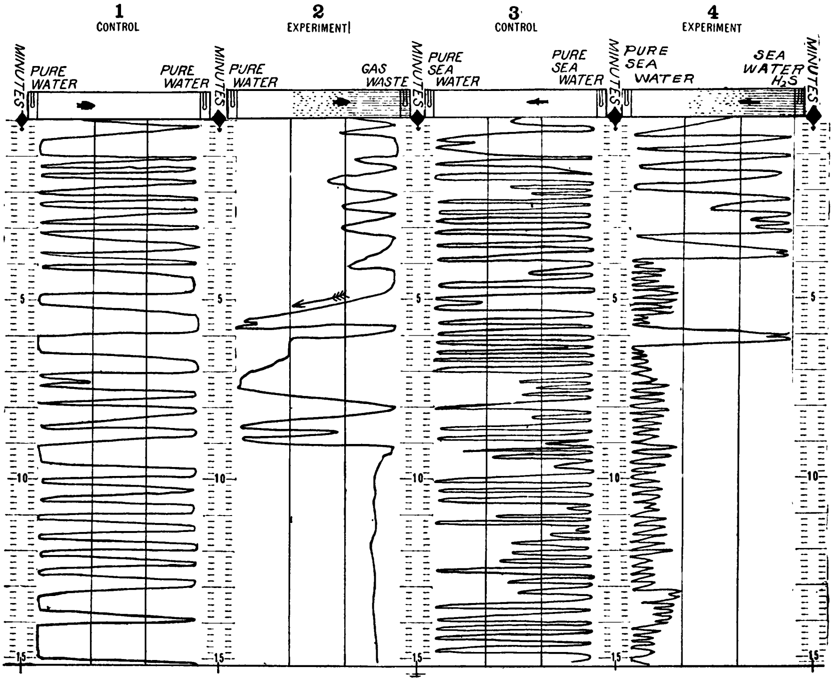


Chart I. Showing the movements of fishes in the gradient tank shown in Fig. 3 (*A* and *B*). Fig. 3, *B*, is repeated at the beginning of each graph; where the water was alike in the two ends it is shown clear. The kind of water is indicated above the figure. The scales at the sides are minutes divided into ten second periods. The fish is shown in black above the beginning of each graph and headed in the direction which the graph shows that it is moving. The back-and-forth movements of the fish are shown by the tracings from right to left in the graph. The length of time spent in moving, turning around standing still is indicated by the time scales.

Graph 1. Showing the nearly regular back and forth movement of a sunfish in pure water.

Graph 2. Showing the preference of the same sunfish for water containing gas waste and its turning back from purer water. The arrow indicates that it was driven into pure water.

Graph 3. Showing the nearly regular back-and-forth movement of herring in pure sea water.

Graph 4. Showing the sharp avoidance of sea water containing a little H_2S, after a few trials of the entire length of the tank.

in the treated water. In either case they are called *negative.*

Several species of fish,—large and small mouthed black bass, green sunfish, blue gill, crappie, golden shiner, sucker, and various minnows, were studied in detail. All these fishes were slightly negative or indefinite in their reaction to water containing little dissolved oxygen, *i. e.*, they turned back from or ignored water of low oxygen content. All the fishes were decidedly negative in their reaction to increased carbon dioxide. The differences tried varied from 5 c.c. (⅓ cu. in.) to 60 c.c. of dissolved gas per liter above that in which the fish had been kept. When increased carbon dioxide accompanied low oxygen the negative reaction was very marked; the fishes turned back when the gradient was encountered and only rarely entered the part containing the highest carbon dioxide and lowest oxygen.

Several workers have shown that carbon dioxide is very toxic to fish. It appears to be much more so than corresponding differences (24 c.c. per liter) in oxygen content. Fishes turn away when they encounter an increase of as little as 2 c.c. per liter. Since a large amount of dissolved carbon dioxide is commonly accompanied by a low oxygen content, and other important factors, the carbon dioxide content of water or more precisely the acidity or hydrogen ions (strongly alkaline waters excepted) is probably the best single index of the suitability of that water for fishes. Most species probably can not live where it exceeds 6 c.c. per liter during the breeding season.

2. *Breeding Requirements of Fresh-Water Fishes.*—Nearly all fresh-water fishes deposit eggs on the bottom. It is to the bottom that the dead bodies of organisms sink and decompose and, accordingly, at or near the bottom that poisonous products of decomposition occur in greatest quantity. Decomposition of the bodies of plants and animals results finally in gases such as ammonia, carbon dioxide, hydrogen sulfide, methane, etc., which diffuse rather slowly to the surface and into the atmosphere, and in blackened organic débris called humus. Thus the extent to which the gases occur is dependent upon the amount of decomposition and the circulation of the water. The same processes of decomposition which result in these gases consume oxygen and as a rule there is insufficient oxygen for eggs and young fishes. A small addition of organic matter may readily decrease the oxygen and raise the carbon dioxide to a point which weakens the eggs and favors fungus.

If a body of fresh water is to support the most desirable fishes it should have an area of clean sand, gravel or other terrigenous bottom covered by from six inches to two feet of water and an area of emerging and submerged vegetation to supply food. It is probable that for the best results these three areas should be about equal. The terrigenous bottom should usually be free from blackened débris (humus), for this usually accompanies decomposition. There is nothing deleterious about humus provided the material in it has passed the early decomposition stages. Thus darkened bottom usually, though not always, indicates decomposition and bad conditions. Small quantities of débris may be eaten by débris-eating animals. The presence of gilled snails of the genera *Pleurocera* and *Goniobasis* in fresh water indicates clean bottoms. Various other organisms usually indicate pollution with sewage.

For many fishes an area of water more than four feet deep is relatively unimportant. The addition of sewage and other organic matter affects bottoms and therefore breeding conditions most. The young at the time of hatching are perhaps more sensitive than eggs, certainly more so than adults.

The destruction of breeding grounds in the Great Lakes is credited with the depletion of the whitefish supply. In 1871 Milner dredged eggs of the lake trout together with decaying sawdust. The eggs were attacked by fungus. In 1908 Clark expressed the opinion that through the accumulation of slow decaying woody material, water-logged lumber, and sewage, the chief breeding grounds of the Great Lakes had been destroyed and could not be recuperated. If the warning of Milner thirty-five years earlier had been heeded, they would have been much better than at present.

3. *Relation to Pollution.*—Sewage without the addition of industrial wastes merely consumes oxygen, and increased carbon dioxide and ammonia to a point where fishes can not live. It is particularly damaging to the young on account of its destruction of breeding grounds and production of conditions which can not be tolerated by newly hatched fishes. The introduction of sewage also favors the growth of fungi which destroy the eggs of fishes. Adult fishes usually avoid such contamination and hence, except where escape is not possible, adult fishes are not killed by it. Rivers receiving the sewage of large cities are rendered uninhabitable to fishes by the development of poisonous compounds just noted. The sewage of Chicago has rendered the Illinois River uninhabitable to fishes as regular residents for a distance of over 100 miles down stream. Some invertebrates are often able to live in rapids where sewage occurs because of the general aeration of the water.

The resistance of different useful aquatic animals to polluting substances varies greatly, as does also that of their living food. In the case of fish, for example, it is not sufficient to secure for making tests any fish that may be convenient. The tests of toxicity must of course be of a character to determine means of affording protection to fish, but not to fish alone; the organisms on which they feed are perhaps commonly more sensitive than the fishes themselves.

The following table, based largely on the work of Dr. M. M. Wells, gives an estimate of the relative resistance of several widely distributed species of North American fishes. While it needs careful verification by new methods, it will serve as a rough provisional guide. It is based largely on death in waters containing little oxygen and much carbon dioxide. Since fishes rank differently in resistance according to the poison in which they are killed, the immediate need for further investigation is obvious.

TABLE I

Indicating the relative resistance of a very sensitive minnow and of some common game-fishes of the eastern and central United States and of the goldfish. The resistance of the least resistant species is arbitrarily taken to be unity

Species of Fish	Relative Resistance	Species of Fish	Relative Resistance
Labidesthes sicculus (Brook silverside)	1	*Ambloplites rupestris* (Rock bass)	10
Moxostoma aureolum (Red-horse)	2.3	*Perca flavescens* (Yellow or American perch)	10
Catostomus commersonii (Common sucker)	2.4	*Lepomis humilis* (Orange-spotted sunfish)	12
Micropterus dolomieu (Small-mouthed black bass)	5	*Carassius carassius* (Goldfish or Crucian carp)	12
Micropterus salmoides (Large-mouthed black bass)	6	*Lepomis cyanellus* (Blue-spotted sunfish)	15
Pomoxis annularis (White crappie)	8	*Ameiurus melas* (Black bullhead)	45
Pomoxis sparoides (Black crappie, Calico bass)	8		

Tests of the minimum quantity of poison which will prove fatal must be made on the most sensitive stage. The strength of a chain is the strength of its weakest link. A little has been accomplished in the study of poisons; the most sensitive period is not known for a single fresh water species of which the entire life cycle has been definitely studied. There is only a little information relative to fishes of different ages.

TABLE II

Showing the relative resistance of different sizes of two species of fresh water fishes. Based on work by Dr. M. M. Wells

Species	Condition	Weight	Relative Resistance
Rock bass	CO_2 and low O_2	1.9 gram 20–40 grams	1.00 5.00
Common shiner	CO_2 and low O_2	0.6 gram 21.0 grams	1.00 3.00

The matter does not end with these biological differences but the toxicity of different substances differs greatly.

TABLE III

Showing the relative toxicity, on a basis of weight, of different substances when added to distilled water. The figures are only approximate, but the great toxicity of acids and alkalies is evident. The higher the figure the greater the toxicity of the substance. All are compared with common salt, which is taken as 100 based on gold fish work by Dr. Powers

Animals Tested	Poison	Relative Effect	Poison	Relative Effort	Poison	Relative Effect
Fresh-water fishes (based on amount required to kill in 45 min. to 3 hrs.)	Common salt . .	100	Calcium acid sulfite	10,000	Magnesium sulfate	15
	Hydrochloric acid	40,400	Potassium chloride	50	Ammonium sulfate	400
	Sulfuric acid . . .	15,000	Calcium chloride. .	59	Sodium nitrate . . .	54
	Nitric acid.	23,000	Barium chloride. .	60	Calcium nitrate. . .	118
	Carbonic acid . .	3,700	Magnesium chloride	77	Magnesium nitrate	105
	Slaked lime. . . .	15,000	Ammonium chloride.	300	Ammonium nitrate	232
	Ammonia.	30,000				
	Calcium sulfite .	22,000				

The great toxicity of acids is evident. The addition of acid to water containing carbonate is accompanied by the liberation of CO_2 and though its toxicity is only about one tenth that of mineral acids, it may be released in quantities very harmful to fishes. In all such cases the precise hydrogen ion concentration should be determined. Limestone is often used to neutralize acid, sometimes to doubtful advantage.

Just after the beginning of the European war the writer undertook the investigation of the effects of wastes from the manufacture of illuminating gas upon fishes. This form of pollution is common in the streams and is probably one of the most important on account of the extremely poisonous character of the coal tar compounds. The most valuable compounds are most poisonous. Benzene, xylene, toluene are used in making explosives and hence of much value, and at the same time they are the most poisonous compounds occurring in the wasted gas liquor in the gas plants. These substances are usually referred to as insoluble and hence likely to be regarded as not of importance in causing the death of fishes. All, however, are slightly soluble in distilled or ordinary stream water. The amount going into solution readily kills the best food fishes in a few minutes. Tarry material holds much of these substances in solution and continually gives it off. Carbon monoxide is one of the most poisonous substances in gas and remains in standing water exposed to the air and continues to kill fishes for weeks. Naphthalene (moth balls) is extremely poisonous, commonly called insoluble, but is soluble enough to kill fishes very quickly. Representatives of nearly all the groups of compounds found in coal tar and gas liquor are deadly to fishes and 90 per cent. of the deadly compounds do not repel fishes (Chart I., Graph 2). When they encounter these compounds, they do not turn back but swim into them. Afterward on encountering pure water they turn back into the poison though it causes death within a few minutes. Mixtures of the compounds are equally or more deadly. Gas liquors, tar " drip " from the pipes are very toxic, 2–40 parts per million kill the more hardy species of fish in an hour. The wholesale destruction of fishes by these wastes occurs at times especially during cold winters. The remedy for this is the complete recovery of all coal products.

4. *Examples of Destruction of Fresh-Water Fishes.*—In January, 1916, in a small river below a town of 50,000 inhabitants large numbers of dead fishes appeared at breaks in the ice. Others in a half intoxicated state were caught through holes in the ice. Three thousand pounds of fish were caught in three days but could not be eaten because of a bad taste said to resemble gas waste. The case was investigated by the Illinois Water Survey. The death of the fish according to their report was due to lack of oxygen and poisoning due to stream pollutions, brought about by sluggish flow and heavy ice cover which prevented aeration. A similar occurrence with less destruction of fish was investigated by the same bureau but the destruction was less, probably due to gas waste not being present as in the first case.

Another case investigated by the writer occurred in a large creek when covered with ice. Fishes in a half intoxicated condition came to holes cut in the ice. Many fishes were taken but proved inedible because of a bad taste. When the ice went out

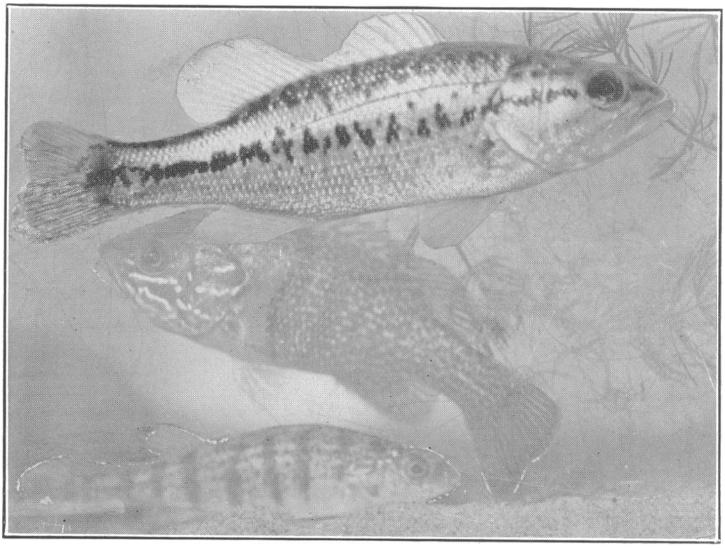
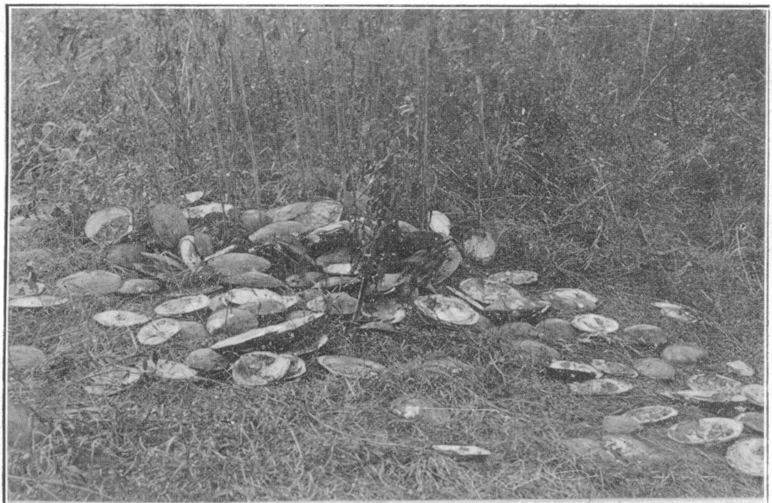


FIG. 4. Fishes common in the Calumet River before sewage was introduced. The upper fish in the foreground is a young large mouthed black bass. The central fish is a half-grown blue-spotted sunfish and the bottom fish is a small perch.

dead fishes were numerous, including carp, large and small mouthed black-bass, crappies, and sunfishes. The bullheads were the only ones which were not killed. There was a bright iridescent film under the ice and an odor of coal gas. This point is 25 miles below a community of 25,000 with a gas plant that pumps gas liquor on to the ground where it gets into the drainage sewers and into the stream. The point where the fishes were killed is a state fish preserve with special penalties for anything but very restricted fishing! The gas plant which is probably to be credited with destroying the fish did not recover anything but the heavy tar. The valuable hydrocarbons, ammonia, etc., are wasted. The destruction of fishes by industrial waste has been common throughout the country, especially within the past thirty or forty years. The fishes destroyed include those which occurred in commercial numbers, such as shad, salmon and whitefish and numerous game fishes such as perch, black-bass and sunfishes shown in Fig. 4. These disappeared in the Calumet River for a long distance below the point of introduction of sewage. Mussels (Fig. 5) survived in the rapids (Fig. 6) only a mile below the entrance of a large sewer. This is possible probably on account of the aeration of the water. The treatment of sewage with compressed air in the presence of activated sludge is effective in reducing its toxicity to fishes.



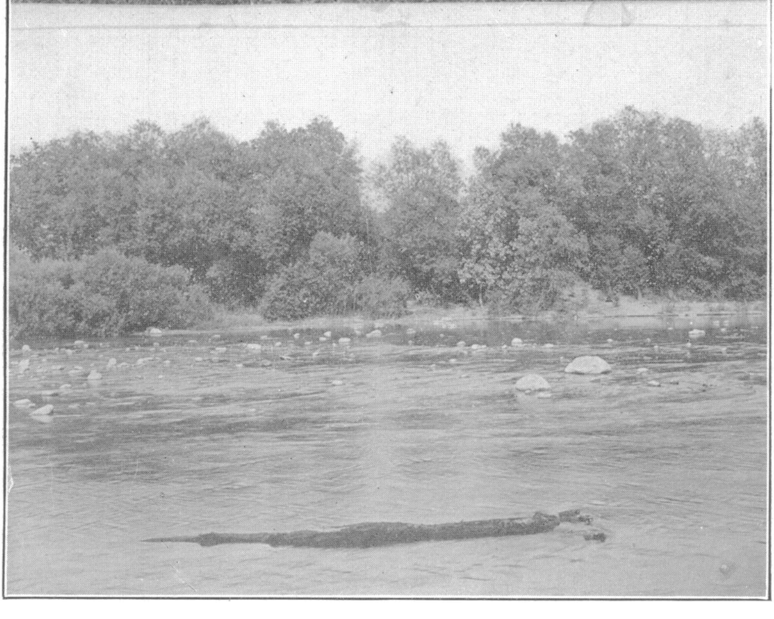


FIG. 5. Mussel shells on the bank of the Calumet showing the work of the pearl hunters. They were taken from the rapids shown below in Fig. 6. The mussels have survived the sewage which enters a mile above, probably because of the aeration at this point.

FIG. 6. Showing the Calumet River at the point mentioned above. The log in the foreground is blackened with sewage.

III. MARINE FISHES

1. *Their Needs*

Marine fishes are comparatively less resistant than fresh-water fishes to the products of decomposition in salt water which results in carbon dioxide and hydrogen sulfide. On the whole the presence of a small quantity of carbon dioxide (lowered alkalinity) in the water affects the fishes less than a smaller amount of hydrogen sulfide. The combination of hydrogen sulfide and carbon dioxide was most rapidly fatal. Since decomposition yields carbon dioxide, consumes oxygen, and is accompanied by the production of hydrogen sulfide which also consumes oxygen, it is reasonable to suppose that on a bottom from which vegetation is absent and decomposition actively takes place, a fatal combination of lack of oxygen, and presence of hydrogen sulfide and probably carbon dioxide can develop quickly. In enclosed arms of the sea when circulation is cut off in the summer, oyster beds are sometimes killed by the presence of quantities of hydrogen sulfide. The destruction of fishes is probably not common, however, because of their negative reaction to it.

2. *Reactions of Marine Fishes*

A. *Hydrogen Sulphide.*—Herring turn back sharply from all concentrations of hydrogen sulphide not great enough to cause intoxication (Chart I., Graph 4). They avoid it sharply and turned about at a point where the concentration was equal to that under the *Ulva* on the sandy bottoms of a bay. The controls (Chart I., Graph 3, and Chart II., Graph 5) of these experiments are symmetrical, there being turnings from each end in about equal numbers. It shows the reaction of the fishes when no stimuli are encountered in the tank.

B. *Salinity and Hydrogen Ion Concentration.*—The fresh water supply of the Puget Sound Biological Station, when the experiments were performed, was from deep wells. It was very alkaline, containing no free carbon dioxide and only 0.5 c.c. per liter of oxygen. This water was aerated, which raised the oxygen to 4.8 c.c. per liter. This water was run into one end of the gradient tank and sea water into the other. In the experimental tank the difference between the density of the fresh and salt water was so great that the fresh water extended nearly to the opposite end at the top with very little mixing and the salt water occupied a corresponding place on the bottom. Thus there was a sharp gradient from top to bottom, but a very imperfect one from end to end. To avoid this difficulty a screen inclined cage was used (see headings of Graphs 6 and 7, Chart II.). The fish moved back and forth in this at a distance of about 4 cm. from the lower screen. The gradient of salinity between the acid sea water and the alkaline fresh water was essentially perfect as shown in Chart II., Graphs 6 and 7; the oxygen content was essentially the same throughout. The salinity in the salt water end was two thirds that of normal salt water and one third in the fresh water end. Phenolphthalein indicator showed that the central region had about the hydrogen ion concentration of sea water (pH 8.0). It appears from a number of experiments that the herring selected either brackish or quite alkaline water (pH above 8.0).

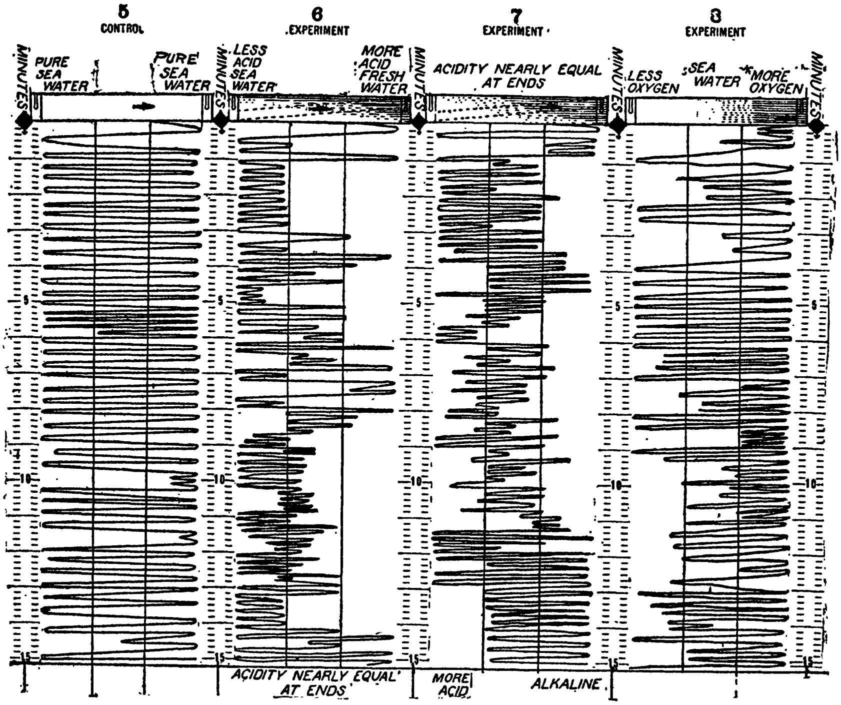


Chart II. For general remarks see Chart I.

Graph 5. Showing the regular back-and-forth movement of a herring in pure water.

Graphs 6 and 7. Showing the selection of a less acid water and the shifting of the position of the fish from the left to the right hand end as the acidity slowly changed. In this case the herring selected the alkaline fresh water, ignoring the salt which is important to marine animals. The fish was confined between inclined screens because of the difference in density of fresh and salt water.

Graph 8. Showing the selection of water with most oxygen by a herring.

To determine whether or not this peculiarity is a reaction to salinity or alkalinity, the experiment with herring was repeated and carbon dioxide to which the fish are negative run in the fresh water, to neutralize the alkalinity. At the beginning of the experiment shown in Chart II., Graph 6, the carbon dioxide content of the fresh water was 26.5 c.c. per liter (probably about neutral pH 7.0) and the reaction was very sharply negative to fresh water. The concentration of the carbon dioxide in the fresh water was gradually lowered and the avoidance fell off, as is shown in Graph 7, which was really only a continuation of Graph 6 interrupted to take a sample which showed the carbon dioxide content to be 8.1 c.c. per liter. During the period represented by Graph 6 the negative reaction decreased gradually until a point was reached when the tank was probably about the same throughout, after which the fish became negative to the sea water at the end of 13 minutes, when on the basis of a uniform decrease, the sea water, which often has an hydrogen ion concentration somewhat greater than "normal" sea water which the herring usually prefers, became more acid than the fresh. Thus it appears that these fish are as sensitive to acidity as litmus paper. The young hump-backed salmon reacted similarly. They had just left fresh water and were caught at sea.

The relation of the two species of fishes to salinity is interesting in this connection as they ignored enormous differences entirely and reacted only to acidity and alkalinity (the herring being able to recognize the difference between pH 8.0 and 8.1). The salmon goes into fresh water to breed and some may reach maturity there or they may return to salt water at varying ages. The orientation of these specimens with head in the fresh water is of interest but it was evident that it was with reference to acidity and alkalinity (hydrogen ion concentration) rather than salinity. Sea water is less acid than the fresh water of salmon streams and the reactions of the salmon accord with their recent entrance into salt water.

The oxygen in the sea water in use at the station never reached saturation. One experiment was tried with water drawn directly from the tap, against water aerated by running over a board. The fishes selected the aerated water; the preference (Chart II., Graph 8) for the higher oxygen content was decided.

The resistance of different species of marine fishes differs as it does in the case of fresh-water fishes. Table IV. shows the relative resistance of several Pacific coast species.

TABLE IV

Showing the relative resistance of several species of Pacific Coast fishes

Hypomesus pretiosus (Surf smelt)	1
Clupea pallasii (Herring)	1.2
Cymatogaster aggregatus (Viviparous perch)	6
Psettichthys melanostictus (Flat fish)	18

3. *The Breeding Requirements of Marine Fishes*

The importance of factors which kill fishes is greatest in the early stages for three reasons. First, the small size of the eggs and embryos makes the ratio between volume and surface smallest and thus any substance in solution will reach all parts of the organism at a most rapid rate. Secondly, the inability of the eggs and embryos to move about makes them the easy victims of any adverse conditions that may occur. Thirdly, the resistance of the eggs to fatal concentrations of poison decreases to the time of hatching, being least then and rising as the fish grows larger. The eggs of the herring are deposited on the bottom. Nelson mentions rocks only and rocks are usually swept fairly clear of organic matter and the water well aerated down to the depth of one fathom where the fishes breed. If this means that sandy bottoms of bays are avoided, it prob-

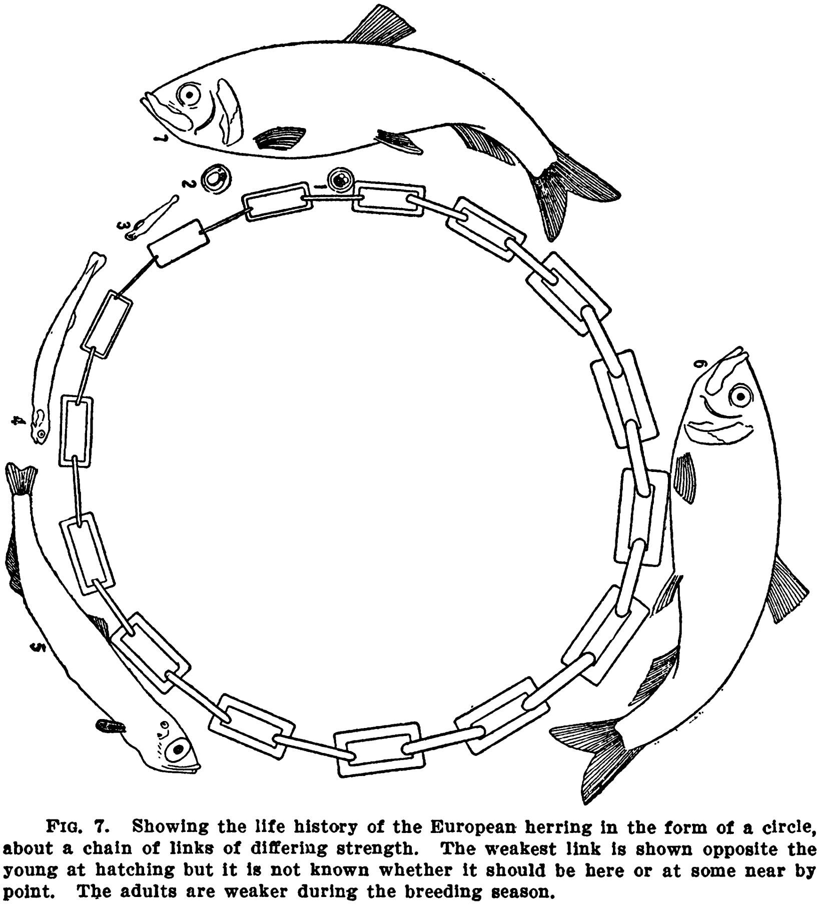


FIG. 7. Showing the life history of the European herring in the form of a circle, about a chain of links of differing strength. The weakest link is shown opposite the young at hatching but it is not known whether it should be here or at some near by point. The adults are weaker during the breeding season.

ably includes the avoidance, during breeding, of water containing much hydrogen sulfide which would be fatal to small herring fry to a greater degree than to those studied, which were 6 cm. long. Sensitiveness to hydrogen sulfide is a matter of much importance from the standpoint of the suitability of a given arm of the sea for herring and the influence upon fishes of contamination of the shores with refuse from the land. Acidity is not great in such shallow water on account of the absorption of CO_2 by the numerous plants for photosynthesis. However this does not prevent the development of much acidity at night. The eggs of nearly all marine organisms that have been studied require alkaline medium (pH above 7.0) for development. This has been demonstrated, for sea urchins, starfishes and plaice.

In the case of marine animals as in the case of fresh water ones there is a most sensitive stage. For fatal doses this falls at some time in the early free swimming stages or about the time of hatching. In the case of weaker concentration the youngest developmental stages of the egg appear to be most easily injured and rendered abnormal, which is often quite as detrimental to the species as fatal doses. Both types of effect are shown below in Table V. The life history of any animal may be represented as an endless chain (Fig. 7).

TABLE V

Showing differences in sensitivity of various stages of several marine animals. Most sensitive stage rated as 1. No basis for a comparison of the species. Based chiefly on the work of Prof. Child and of Whitley on plaice eggs

Species	Poison	Relative Resistance of Different Stages		Criterion
Starfish	KCN	Unfertilized egg	9.00	Fatal dose
		Blastula to gastrula	1.00	
		Young bipinnaria	2.00	
Sea-urchin	KCN	Unfertilized egg	3.88	" "
		Early gastrula	1.00	
		Prepluteus	1.50	
Clam-worm	KCN	2–4 cell stage	18.00	" "
		Larva with 2 pairs of setæ	1.00	
		Advanced larva	3.30	
Killifish	Phenyl urethane	2-cell stage	6.00	" "
		Hatching	1.00	
Tautogolabrus	Phenyl urethane	15 min. after fertilization	43.00	" "
		Heart beating	1.00	
		Newly hatched	1.25	
Plaice eggs	Acid	Fresh-laid	1.00	Unsuccessful development
	Acid	10 days old	10.00	
Plaice eggs	Alkali	Fresh-laid	1.00	Unsuccessful development
	Alkali	10 days old	2.00	

Different inorganic substances differ greatly in their toxicity to marine animals; acids are much more toxic to marine than to fresh water animals.

TABLE VI

Showing the relative toxicity—on a basis of weight—of different substances in distilled water. The great toxicity of acids and alkalies is evident. The higher the figure the greater the toxicity of the substance. All are compared with common salt, which is taken as 100. Based on the work of Prof. A. P. Mathews

Animals Tested	Poison	Relative Effect	Poison	Relative Effect
Marine *Fundulus* eggs (based on least fatal dose)	Common salt..........	100	Strontium chloride....	53
	Hydrochloric acid......	249,500	Sodium sulfate........	97
	Potassium chloride.....	70	Sodium nitrate.......	69
	Calcium chloride.......	185	Potassium nitrate	38
	Barium chloride	56	Sodium hydroxide....	14,610
	Magnesium chloride....	113	Potassium hydroxide..	6,200
	Ammonium chloride....	88	Barium hydroxide....	8,100

The sea water has an extraordinary capacity to neutralize acid. A liter of sea water will almost neutralize a liter of one five-hundredth normal acid and thus the toxicity of acid as shown in the table for pure water is greatly exaggerated as compared with additions to the sea.

4. *Examples of the Effect of Pollution, etc.*

(*a*) *Herring.*—By the method just described it is possible to obtain unusually accurate data on the factors influencing the movements of fishes. According to Marsh and Cobb a great difficulty in the herring fishery of the north Pacific coast is the erratic movements of the fish. Schools may visit a bay for three or four years, in succession, and then, without any apparent reason, avoid it for a season or two altogether. Bertham noted a possible relation between the abundance of these fishes and weather and suggests that climatic causes may have more to do with the failure of some branches of the fisheries than is generally believed. He attributed the failure of the fisheries of Cape Benton to the occurrence of severe east and northeast storms during the running season. It is clear that such storms may affect the dissolved content of the water by raising decomposing matter from the bottom. The English investigator Johnstone has said that it is now nearly certain that the shoaling migrations of the herring of Europe are to be associated with the salinity and temperature of the sea, but it is evident from the experiments described above that acidity and alkalinity are more important than salinity and the solution of the problem will come from a careful study of the reactions of fishes along with a similar study of conditions in the sea.

The extreme sensitiveness of the fishes studied, as shown by their detection of slight deviations from neutrality, of small fractions of a cubic centimeter per liter of hydrogen sulfide, etc., makes it very clear that there is no difficulty in fishes determining the direction to large rivers from hundreds of miles out at sea or of finding their way into any bay or harbor or river or other arm of the sea which their particular physiological condition at a given time demands. It is not necessary to appeal to "instinct" to explain the return of certain salmon to certain rivers, or the running of herring in certain localities. The mere fact of their origin in the region, the probably limited tendency to leave it coupled with their ability to detect and follow slight difference in water is a sufficient explanation of all their peculiar migrations. The close way in which animals stay about certain localities from generation to generation is hardly appreciated. Thus, as Johnstone points out, the herring of the east coast of Britain are largely local, having formerly been assumed to belong to shoals that came from distant points.

The experimental method can not of course determine the cause for the absence of fishes from any given point but must be accompanied by hydrographic studies. Such combined efforts give trustworthy results. Hydrographic studies alone may lead to entirely erroneous assumptions because of the lack of knowledge of the sensibilities of the fishes concerned and the selection of some insignificant factor correlated with their absence or presence, as an explanation. Such correlates, offered as explanations, become the basis of erroneous remedial measures.

Noting the remarkable discriminations of fishes for differences in alkalinity, acidity and neutrality, a note of warning may be sounded in regard to the relation of pollution to runs of herring. The avoidance of the decomposition products is a sufficient explanation of the absence in valuable numbers of many other fishes. Their tendency to avoid acid waters, hydrogen sulfide, etc., which result from decomposition and are increased by the presence of refuse of fish canneries, sewage, etc., makes diversion of such refuse from the sea an important consideration. The Baltic towns of the Hanseatic League were dependent in part upon the herring industry and after a century of great growth and prosperity fell into decline at the middle of the fourteenth century. Their prosperity was the accompaniment of the presence of great shoals of herring off the Island of Rügen in the Baltic. Their decline was caused in part by the failure of the herring industry and the supposed migration of the herring to the North Sea which has since been the center of the industry. Schouwen (on the Netherland coast of the North Sea) appears in the fourteenth century to have been frequented by the herring shoals in preference to Rügen. The rapid growth of the Netherland cities, their supremacy and final separation from the Hanseatic league followed. A little later the herring again changed their haunts, choosing the coast of Norway, where both Norsemen and Netherlanders caught them. The Beukelszoon method of curing herring having come into use, nearness to home was no longer a necessity. The Norse fisheries flourished until 1587, when an "apparition of a gigantic herring frightened the shoals away." Thus it appears that the development of the herring industry in each locality led to desertion of the locality by the fish, though the migrations assumed by historians are doubtful. Was this due to the contamination of the sea by the cities, or merely to over catch? Whichever may have been the case it is certain that contamination will not invite runs of the herring.

(*b*) *Cod.*—The cod eggs are pelagic and usually deposited in December or during the winter. The development takes place in the shore waters. The reduction of the cod supply of New England was associated with the building of dams across all the principal rivers and was attributed to the shutting out of the alewives, salmon and shad which were important articles of diet of the cod. It is far more likely that the construction of large factories which poured refuse into the sea destroyed the eggs through the lowering of alkalinity which prevents development.

IV. PRESENT DAY PROBLEMS AND THE WAR

The present great increase in manufactures and the excessively cold winter of 1917–18 with sluggish flow of streams may be expected to decrease available food fishes in inland waters. Industries using coal, gas plants, etc., are throwing much waste into streams which will destroy fish, not because they do not appreciate its value, but because being unprepared for peace they are unprepared for war.

Recently the gas company in the city of X with 25,000 inhabitants could not work up certain of its gas by-products and was storing them in reservoirs. If a market has not opened, this will find its way into the nearby stream. There was at the outbreak of the war no adequate market for coal, oil or water gas by-products. We have been and are still destroying or throwing away our most valuable coal-gas by-products. Material for munitions in enormous quantities were cast into our streams to bring untold destruction to fresh-water fishes before the war began. Until very recently under the pressure of the war there was no attempt to save these gas by-products from the smaller plants. Since interest in the by-products is increasing, many plants have attempted to save more than tar. Most of the small plants are entirely unadapted to save anything but heaviest tar and gas. The rest, with its innumerable valuable dyes, drugs, flavoring substances and explosives, is still cast into streams to kill fishes! Shortly before the war less than 25 per cent. of the coal coked in the United States was coked under conditions of complete recovery of all products. Now the percentage has increased to about fifty.

In the study of effects of pollutions on useful aquatic animals there has been too little in the way of clear statements of the problems involved. Under the pressure of the questions brought forward by the war, the writer has formulated the following nine questions involved in the solution of pollution problems.

1. In the study of the effects of pollutions test animals must be used. Is the animal selected one of representative sensitiveness? The tables on fishes (pp. 108 and 115) show the need of care in selecting test animals. The common suckers are recommended as suitable fresh-water animals for tests. They are widely distributed, easy to obtain, easy to recognize, and are representatively sensitive. It is also comparatively easy to determine accurately when an individual is dead. Dr. Powers found that to touch the tip of the tail of a fish to acid would determine whether or not it was dead. Herring are representatively sensitive marine fishes.

2. What is the most sensitive stage in the life history? (See pp. 109 and 117.)

3. When is the pollution most concentrated?

In fresh water, pollution will, as a rule, be most concentrated during seasons of drought or in extreme low water in winter; but to this rule there are many exceptions. Pollutions which float will do most damage during storms or high winds. This source of danger is greatest in the sea. Ice in winter prevents aeration and hinders circulation, and seems to have been responsible in Illinois for important losses of fish due to pollution. Many poisons are more toxic at high temperature than at low.

4. What is the toxicity of untreated polluting effluents; of each residual of processes of partial recovery; or of treatment by additions to the effluent? This can be determined by extensive experimentation only.

5. Do animals turn back from the polluting substance and thus escape destruction, or do they swim into it and die? (See p. 105.)

The acids from munition works have attracted attention of late. An effluent composed of 0.13 to 0.4 per cent. of acid—a mixture of 2 parts of sulfuric acid and 1 part of nitric acid—is discharged by guncotton works. This acid effluent flowing into the brackish waters of the coast of New Jersey repelled the killifishes, on which the keeping down of mosquitoes depends. It was proposed to treat the acid effluent with lime, and the question of the effect of the calcium nitrate on marine fishes became a problem for immediate solution. A number of tests of herring and viviparous perch in the summer of 1918 showed that they are attracted by the calcium nitrate. Similar problems are arising in connection with inland rivers. Large quantities of such acid is now being run into the Sangamon River by munition works at Springfield, Ill., and into various other waters of that State.

6. Do polluting substances cover the bottom and make conditions unfavorable for eggs?

The majority of important fresh-water animals—mussels, which furnish pearl for buttons, whitefish, bass, sunfish, etc.—are dependent on the bottom for breeding, living conditions or food. If the contaminating substances are covering breeding bottoms of bare sand and gravel they are dangerous to fishes.

7. If the supply of useful animals is depleted will recovery be rapid or slow?

Petersen and Jensen found that if the flora and fauna were removed from marine bottoms useful animals such as oysters can not again live on them until a series or succession of plants and animals has prepared the way. The same is true of fishes in fresh water. A body of water deprived of all its vegetation, with the associated animals, requires much time for recovery. It is not simply the useful animals that must be taken into consideration, but the entire association of plants and animals.

8. Can correct decisions be reached without investigation of individual cases which arise?

Decisions relative to all the preceding points must usually be reached on the ground. Waters differ in their capacity to neutralize the effects of effluents, in the maximum and minimum flow, and in their dissolved content. Samples of water should be taken with reference to the particular animal-problem in hand.

9. What is the real value of the waste when the amount of the damage which it causes is added to its commercial value?

One continually hears it said that the recovery of this or that waste product does not pay; this is an all-sufficient reason for not recovering it and the matter is usually dismissed forthwith. We need an entirely new view-point, and a new system of bookkeeping. The value of any waste product is its commercial value, when properly recovered, plus the amount of loss it occasions when unrecovered. Practically all kinds of waste may be made into something useful. Why is it not recovered? I attempted to answer this question when asked by myself of a widely known consulting engineer the other day, by saying that it would not pay. He remarked that, in his experiences, this is not the answer. The manufacturers more often do not care to spend any energy in dealing with the matter. Their object is to do the primary thing in hand and to get rid of the by-products as easily as possible. Here a sense of obligation to act in the interest of the public is needed. It has been estimated that the sewage of ninety-seven cities of more than 50,000 inhabitants, treated by the Miles process, would yield per year as follows:

Fertilizer	97,393,680 tons.
Ammonia	4,869,684 tons.
Grease	25,780,680 tons.
Glycerine	1,289,039 tons.

Recovery plants have not been installed, however, because critics of the conservation plan maintained that the profits will be less than its friends have predicted. As has been true in most other cases, calculations of the cost of suitable recovery plants and of the value of recovered products have probably been made with only minor regard to public health, and with little reference to the damage which the remaining effluent may do to fishes. In correct calculations the value of the recovered products and the benefits to public health would both be regarded as credits. The dangers to fisheries from the residual acid effluent can probably be turned to benefits if sulfur dioxide is used and the residual effluents aerated before being turned into the streams.

Aside from these nine questions which are a basis for the determination of a policy for biologists generally and for fisheries men in particular, the legal situation relative to stream pollutions is peculiar. In most cases there are adequate laws to prevent the contamination of streams, but when the state goes into court with a complaint the offender usually says, "Tell us how to dispose of our refuse without polluting the streams and we will be glad to do so." He usually is sustained by the court, in continuing the nuisance until the complainant has shown how it can be done. In case of most misdemeanors the offender has to invent his own means of stopping the offense, but, in these cases, the state must discover it for him.

A similar condition is found in the consultation of engineers and biologists. The biologist complains of the ill effects of pollution. The engineer says, " Tell us what must be done to save the fishes and we will do it, otherwise we must ignore them." Here, as in the case of legal matters, the responsibility falls on the biologist, and in a large measure where it belongs, as the final test of all methods of treating or recovering polluting substances lies in the effects of the results on animals. These effects must be determined by experimental study. The time is at hand when fresh-water biologists must perform the experiments, discover the fundamental facts and be able to answer all these questions correctly. For sewage disposal both the Miles and the activated sludge processes afford promising points of attack. The wastage of many industrial residues is likely to be discouraged in future, but there is always something left to be turned into streams and the biologist must be at hand to determine the condition of fisheries and other biological interests in respect to them. Soon public opinion will demand these measures; eventually the battle for the fishes will be won, and when we are advised to eat fish we will be able to find them near at hand.